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Review

Climate change, urban ecology, and the worldwide expansion of dengue fever

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Abstract
Unexpected weather patterns that might lead to dangerous situations are a result of climate change. The healthcare system is one of the many sectors impacted by climate change. Climate change will cause several vector-borne infectious illnesses to spread geographically. Dengue is currently causing a lot of damage, and one of the main factors accelerating the spread of the disease is climate change. Rainfall, temperature, and relative humidity are the three main meteorological variables associated with dengue transmission. This article will discuss outcome and correlation between dengue and environment, rainfall, urbanization, climatic and non-climatic factors and wants to derive recommendations.

Keywords: *dengue outbreak, rainfall, global health, water storage, health system*

INTRODUCTION

There are serious and concerning possible effects of climate change on infectious diseases and the humans. Presently, there is no widely recognized and certified treatment or vaccine for dengue/severe dengue fever, one of the most quickly spreading arboviral diseases in the tropical region. The dengue virus (DENV) and its mosquito vector, primarily *A. aegypti* and *A. albopictus*, have expanded rapidly during the past forty years, posing a serious threat to public health in tropical areas [1]. Currently, people in more than 129 countries across the world are at risk of contracting dengue, which is spread by both types of Aedes mosquitoes and accounts for 70% of the disease's global burden. The WHO estimates that there were 5.2 million dengue cases in 2019 and 4032 fatalities annually. These mosquitoes spread the Zika, yellow fever, and chikungunya viruses in addition to dengue [2]. According to many sources and prediction, climate conditions have bearing on the epidemiology of dengue disease. Numerous studies conducted in Latin American and Asian nations, including Taiwan, Ecuador, and Vietnam, have verified a favorable correlation between Aedes and Stegomyia indices abundance. The epidemiological complex, which encompasses vector ecology, pathogen biology, disease transmission, illness occurrence and prevalence, and disease control, prevention, and treatment, may be said to be largely determined by climatic conditions.

Many investigations have revealed a strong and ongoing relationship between climate of an area and the occurrence of dengue [3]. While some disputed any significant influence, others thought the climate would probably have a small but significant impact [4]. By comparing dengue cases with climate data, several models have been developed to predict a possible dengue outbreak [5]. We can better understand and predict the periodicity of epidemics by studying climate variability since the interaction between vectors and the climate is just as important as the relationship between the vector and humans. A growing number of epidemiological research have looked into climate-based statistical and mathematical frameworks that could help explain the cycles of dengue incidence [6].

Dengue and environment

The frequency of dengue disease and climatic factors has a complex connection (Table 1). Rainfall, temperature, and humidity are the most significant explanatory factors in the spread of DENV via vectors (*A. aegypti* and *A. albopictus*) and human hosts, according to a meta-analysis [7, 8]. Aedes mosquitoes, particularly *A. aegypti*, are a form of vector that primarily inhabits various sizes and types of water containers and breeds in clean water. Artificial water containers thus play a crucial role in Aedes mosquito reproduction and dengue outbreaks, particularly in metropolitan settings. Therefore, unnecessary water containers and opened drain, particularly in urban settings, are crucial tools to the spread of dengue through mosquito breeding, life cycle, and DENV infection [9].

Table 1. Summary of environmental factors linked to the spread of dengue

Environmental factor	Impact on dengue	Explanation
Temperature	Enhances viral multiplication and mosquito survival	The mosquito life cycle is accelerated, and the extrinsic incubation period of the dengue virus is shortened by warmer temperatures (25–30 °C)
Rainfall	May promote mosquito breeding sites	The perfect breeding environment for A. aegypti mosquitoes is stagnant water from rainfall. Rainfall that is excessive or erratic can raise the risk
Humidity	Lengthens the lifespan of mosquitoes	High humidity prolongs mosquito survival, increasing opportunities for virus transmission
Urbanization	Increases the habitat of mosquitoes	Mosquito reproduction in artificial containers is encouraged by poor urban planning, insufficient trash management, and water storage techniques
Population density	Facilitates transmission	High density areas allow mosquitoes to bite more hosts, accelerating outbreaks.
Waste accumulation	Offer suitable breeding places	Discarded plastics, tires, and cans collect water and act as breeding sites for Aedes mosquitoes
Changes in land use and deforestation	Alters mosquito ecology	Land use changes may affect the distribution of vectors and bring people closer to mosquito habitats

Numerous studies have forecasted how dengue fever might expand in a warmer world based on the relationship between weather and disease transmission. According to research, there may be a rise in disease transmission and vectorial capabilities in future [10]. Dengue fever has been increasing, and as the disease has migrated to new areas, so too it has potential for quick transmission. Because of the intricate relationship between climatic conditions and disease transmission, patterns of disease epidemics, especially their size and peak time may change because of global warming. For example, it was anticipated that longer future dengue fever epidemics would arise from a longer period of environmental favorability for the dengue fever vector in Europe. Geographic heterogeneity may also cause dengue fever transmission predictions to differ from one location to another. Given that tropical locations like South and Southeast Asia are expected to continue to be more conducive to dengue fever vectors in the future, dengue fever transmission may behave differently than it does today [10]. There has been concern raised about how the increasing incidence of the disease may be attributed to climate change, particularly global warming. Knowing the etiology, transmission, and treatment of dengue fever, as well as the crucial role that Aedes mosquitoes play in its spread may help us better understand how the disease interacts with environmental factors [10, 11].

Rainfall and dengue

There are several intricate, interconnected aspects that affect the correlation between dengue incidence and rainfall. In most nations, dengue epidemics occur during the rainy season and with periods of higher precipitation overall, according to the research on dengue epidemiology [12]. In this context, Kuno [13] observed a favorable correlation between rainfall and dengue incidence and larvae density, which has since been confirmed in several tropical nations. However, because dengue outbreaks follow distinct climate patterns in certain places, this causal path cannot be globally generalized. Additionally, excessive rainfall can have a detrimental effect on vector breeding by washing away the vector breeding habitats, which can then influence over dengue epidemics [14].

Climatic and non-climatic factors for dengue outbreak
Dengue spreads across the world's tropical and subtropical zones. The primary causes of rising diseases incidence and viral geographic extension are climatic and non-climatic variables. Global warming might be one of the unstated causes of this virus's escalation. By shortening the time, it takes for an egg to reach maturity and accelerating viral replication and biting activity, the increased ambient temperature and humidity change the life cycle of vector population (Figure 1). A prolonged transmission period is made possible by climate change brought on by global warming, which lengthens the timeframe for breeding.
Serotype evolution and host immunity are examples of non-climatic inherent factors that contribute to the spread of the virus from urban to rural areas, while socio-ecological factors like unplanned land use, water logging, widespread urbanization, and unrestricted travel from endemic to non-endemic region promote viral transmission.

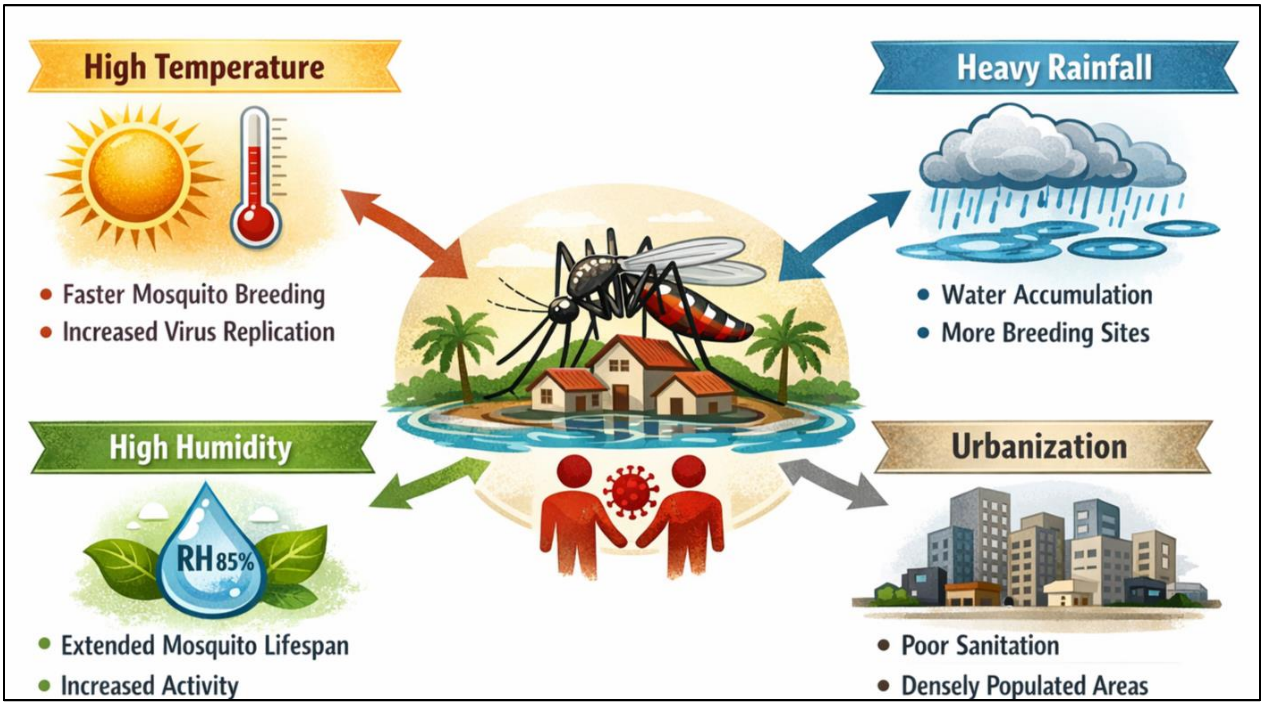

Fig. 1. Climatic factors anticipated for dengue outbreak

Socio-economic status and housing facility
Dengue transmission and socioeconomic level have a complex connection. Research shows that overcrowding, erratic water supplies (which need water storage), and inadequate sanitation infrastructure—such as open drains and inappropriate waste management—put low-income communities at greater risk. Studies conducted in Delhi and Colombo has demonstrated that these circumstances greatly expand mosquito breeding areas [15, 16]. Surprisingly dengue is not completely absent from rich communities. The abundance of beautiful water features, gardens, and potted plants that act as hatching grounds, as well as has the proximity to low-income regions, make wealthy districts in Guangzhou, China, susceptible, according to studies. Similar findings were reported in Rio de Janeiro, where vegetation and poorly maintained water features were associated with increased *Aedes* mosquito productivity in affluent districts [17]. This interconnectedness makes the link between socioeconomic position and dengue risk more complex by demonstrating that, under some circumstances, both high- and low-income areas can contribute to transmission.
Deforestation and shifting land use patterns disturb ecosystems, helping mosquitoes to adapt to human settlements, while urbanization and inadequate waste management intensify these climate-driven consequences by establishing artificial breeding grounds. El Niño event and other climate abnormalities cause irregular temperature and precipitation swings that encourage mosquito growth, which further contributes to dengue outbreaks.

Prospects for dengue fever in the future

The forecasted effects of global warming on the spread of dengue fever to new regions are used to anticipate future trends in the disease and its potential impact on global health. The future course of dengue fever presents a complex and evolving picture for global health. Epidemiologists predict that the future distribution of the illness will be influenced by urbanization, climate change, and international travel.

Consequently, it is anticipated that dengue fever will continue to rise [18]. Aedes mosquito populations rise in tandem with urbanization and population growth. As more people relocate to cities, the risk of dengue fever outbreaks increases, particularly in densely populated areas with inadequate sanitation and waste management. The increase in foreign travel is also responsible for the rapid spread of dengue disease. Because infected individuals may disseminate the virus to new locations, dengue fever may spread to previously uninfected places. Epidemics in previously untouched areas might result from this transcontinental transmission [19].

One serotype of dengue virus infection increases the likelihood of developing a second serotype infection, which can lead to severe dengue infections [19]. Extreme weather and climate change may have an impact on the patterns of dengue disease transmission [20]. In regions where seasonal outbreaks are common, peak transmission periods may alter, enabling the disease to evolve from a seasonal to an ongoing infection. The abundance of vectors that are resistant to conventional insecticides makes it more difficult to tackle them. Because Aedes mosquitoes have the potential to become resistant to insecticides, so that new and long-term vector control methods are required.

Future directions

The escalating impacts of climate change and environmental degradation are intimately linked to the rising frequency of dengue disease worldwide. To reduce the illness burden and foresee changing patterns of transmission, future research and public health initiatives must embrace multidisciplinary, predictive, and sustainable approaches.

The incorporation of climate-based predictive surveillance systems is a crucial future path. The life cycle and dispersion of A. aegypti and A. albopictus mosquitoes are significantly impacted by climate factors as temperature, humidity, and rainfall [21]. More accurate epidemic prediction can be achieved by creating early warning systems that integrate epidemiological surveillance, remote sensing, and meteorological data [22]. These models will continue to be improved by artificial intelligence (AI) and machine learning algorithms, enabling policymakers to implement focused vector control initiatives in high-risk areas prior to the onset of epidemics.

Environmental management and urban planning are two more crucial areas for advancement. Dengue vectors continue to find perfect breeding grounds in unchecked urbanization, inadequate water storage, and improper waste management [23]. Better drainage systems, effective waste management, and the use of mosquito-resistant building materials are all examples of sustainable city designs that should be encouraged by future policies. Urban mosquito populations can be decreased, and general living conditions can be enhanced by implementing green infrastructure and community-based environmental initiatives [24]. Research on mosquito adaptation and vector ecology in response to climate change needs further attention. In temperate areas where dengue transmission was historically uncommon, rising temperatures are allowing Aedes mosquitoes to spread their range [25]. Designing long-term vector control and monitoring systems requires longitudinal research on mosquito evolution, vector competence, and virus adaptation in various climatic conditions.

Climatic driver for dengue in Bangladesh and current situation

The number of dengue outbreaks in Bangladesh is skyrocketing; by October 2025, there were around 50,689 cases reported and 215 fatalities. Experts warn that unless mosquito control is quickly expanded, the outbreak could get worse [26]. The outbreak in 2023 was the worst on record, with about 321,179 cases and 1,705 fatalities [27]. Dengue is spreading into rural areas from urban areas, indicating a geographic expansion of the risk of transmission. The case fatality rate (CFR) is increasing, according to one research, it increased from 0.16 % in 2019 to nearly 0.57 % in 2024 [28].

Extreme rainfall occurrences in Bangladesh are predicted to rise sharply under warming, particularly in the northeast and coastal regions, according to recent „downscaling"research. By the middle of the century, the daily maximum precipitation (for a 100-year return period) might increase by about 50 mm/day [29]. About 80 % of Bangladesh's annual rainfall falls between May and September due to the country's monsoon climate. The timing of outbreaks and mosquito breeding windows can therefore be affected by variations in the onset, length, and intra-seasonal distribution of monsoon rainfall [30]. Bangladesh currently experiences a warm, humid climate that is conducive to dengue. Warmer temperatures also speed up the life cycles of adult mosquitoes and reduce the extrinsic incubation period.

Climate factors including temperature, humidity, and precipitation have a nonlinear and threshold-dependent impact on dengue transmission. For instance, mild warming may increase mosquito transmission, but extremely high temperatures may decrease insect survivability [31]. Extreme event sequences like heatwave followed by heavy rain or co-occurring anomalies (drought followed by flood) can cause unexpected breakouts that are not predicted by single-variable models [32]. The impact of climate change can be amplified locally by urban microclimates (heat islands), inadequate drainage, water storage techniques, and infrastructural weaknesses.

Changing rainfall trends and water storage practices in the urban dengue dynamics

Rapid population expansion, urbanization, and environmental changes have accelerated the spread of disease in recent decades. This is particularly true in densely populated cities where human activity and climate collide. Changes in rainfall patterns and human water storage practices are two of these elements that have emerged as major contributors to the development of dengue vectors and the disease's spread [33].

In many regions of the world, climate change has altered the timing and location of rainfall. The ecology of Aedes mosquitoes is significantly impacted by increased rainfall variability, which is manifested by extended dry spells mixed with periods of intense rain. Puddles, sewers, and abandoned containers are examples of temporary breeding grounds that can be produced by heavy rain. Urban dwellers frequently store water in containers for domestic usage during protracted dry spells. Although these storage techniques are required to address erratic water supplies, they frequently provide Aedes mosquito larvae with perfect environments. Consequently, a cycle that supports mosquito populations' growth even in the face of severe weather circumstances is produced by the interplay between shifting rainfall patterns and human behavior (Figure 2) [34, 35].

This problem becomes worse in urban settings by inadequate waste management, unplanned settlements, and poor drainage. Recurring breeding grounds are produced by clogged drains and stagnant water following rain. In addition, homes end up storing water for a long time due to unreliable distribution. Dengue is more common in regions with both greater rainfall unpredictability and water scarcity, according to research from Asia, Latin America, and sub-Saharan Africa. Additionally, dengue outbreaks might be impacted by the timing and intensity of rainfall. To correspond with the life cycle of the mosquito and the incubation period of the virus, there is frequently a wait of several weeks between rises in cases and rainfall maxima. Understanding how changes in rainfall affect urban water storage is essential for predicting and reducing dengue outbreaks in a shifting climate. Combining weather data, remote sensing, and insights into behavior provides a better way to forecast dengue risk.

Dual burden in dengue vulnerability across low-income nations

Low-income nations are most severely impacted by climate change, which promotes dengue transmission in tropical and subtropical areas. *A. aegypti* and *A. albopictus* can flourish in more places and at more times due to rising temperatures, erratic rainfall, and longer monsoon seasons. These mosquitoes reproduce rapidly in stagnant water and thrive in warm, humid environments. Poor municipal drainage and climate change are making this problem more prevalent. Mosquito breeding grounds are increased in many cities in South Asia, sub-Saharan Africa, and Latin America due to erratic rainfall patterns and inadequate sanitary facilities. Furthermore, crowded neighborhoods that struggle to supply clean water and effective waste management have been produced by rapid urban growth without thorough planning, creating ideal circumstances for mosquito multiplication [36÷38]. All countries are impacted by climate change, however not everyone is equally affected in terms of health. Richer nations have greater infrastructure, vector control initiatives, and monitoring mechanisms to address environmental threats. Low-income countries, on the other hand, struggle because they lack the resources necessary to monitor mosquito populations, forecast epidemics, or implement community control initiatives. The danger and spread of dengue transmission are increased by this climate change susceptibility combined with persistent economic difficulties [39, 40].

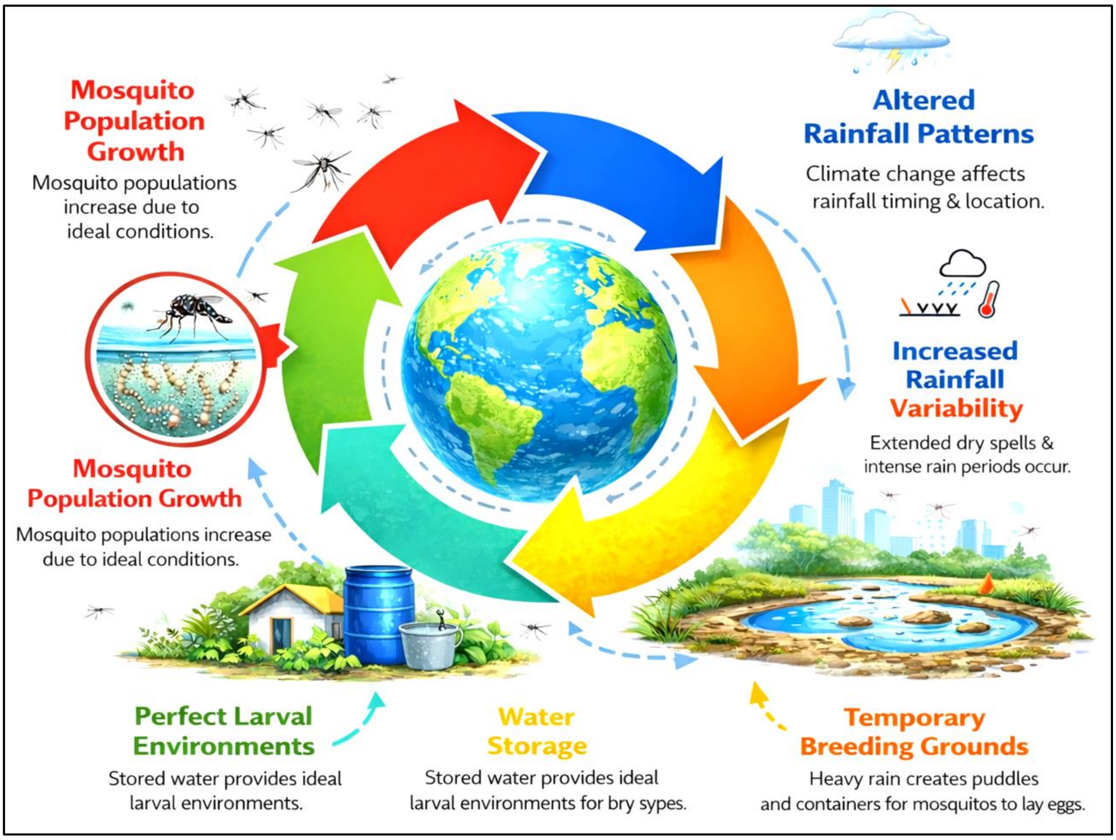

Fig. 2. Environment change and mosquito breeding dynamics

Economic vulnerability extends the impact of dengue beyond immediate illness. When a family in poverty becomes ill, they lose money. Expenses associated with medical care might further strain households' finances. Outbreaks of dengue strain already-fragile healthcare systems and divert funds from other critical services for governments. This results in a vicious cycle whereby poverty raises the risk of illness, which in turn keeps individuals in poverty. Low-income communities are particularly prone to this cycle of vulnerability [41, 42].

Poor health system challenges

Weak health infrastructure makes dengue a bigger threat in resource-limited countries. Many low-income nations do not have strong systems to detect outbreaks early and respond quickly (Figure 3). Laboratories often lack the necessary equipment to confirm dengue cases. This situation leads to underreporting and poor handling of outbreaks. Vector control programs tend to be reactive; they are put in place only after major epidemics happen. In addition, coordination among environmental, health, and local governance sectors is often weak, which hampers comprehensive dengue management [43, 44]. There are several obstacles to public health communication. The effectiveness of awareness initiatives is hampered by misinformation, low literacy, and inadequate community involvement [45]. Preventive actions, such as clearing stagnant water or increasing protective barriers, are inconsistently implemented when local engagement is low [46]. The gap in dengue susceptibility between high- and low-income nations continues to grow in the absence of sustained investment in public health infrastructure and education [47, 48].

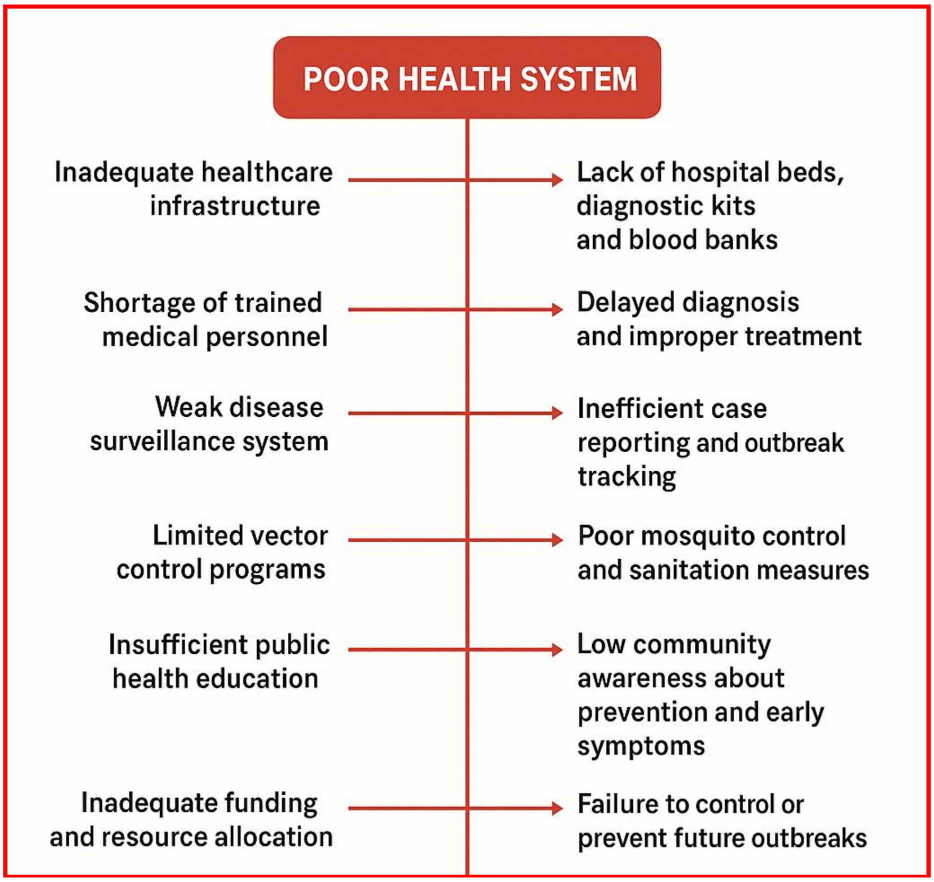

Fig. 3. Poor health system and its impact on dengue outbreak management

RECOMMENDATIONS

Effective monitoring and early warning systems are necessary to detect outbreaks and take prompt response. Creating awareness among public about environmental factors that contribute to the development of Aedes mosquito is essential. In addition, proper hygiene maintenance from individual level and deployment of enough workers to clean the municipality and roadside drain, sewer help to promote that practice. On the other hand, improvements in diagnosis and case management are crucial to reducing the impact of severe dengue infections. It's probable that continued efforts to develop more effective dengue vaccines will be essential to stopping and managing the disease. A thorough comprehension of the dynamics of viral serotype transmission may improve disease epidemic prediction and, consequently, control. Monitoring, illness severity prediction, and patient care will all benefit from the molecular identification and characterization of viral serotypes. Recurrent dengue outbreaks can be prevented by focusing on strategic vector control, managing socioeconomic reasons, early serotype diagnosis, and illness severity prediction. People living in rural areas always have limited access to healthcare facilities, so proper distribution of medical equipment and physicians to rural areas would facilitate to resolve this discrepancy.

Despite the progress, a vaccine suitable for broad use has not yet been identified. The scientific challenges of multiple dengue viral serotypes, immune imprinting from previous infections, and immune enhancement of infection and disease remain formidable obstacles to this goal [49]. If the population has access to safe and efficient vaccinations, the incidence of dengue disease may in decline. It is anticipated that dengue fever would keep increasing, putting pressure on public health systems across the world [50, 51]. A concentrated and coordinated effort combining advanced vector control techniques, climate-resilient strategies, and improved healthcare measures is required to solve these challenges [52].

It should be mentioned that the Standing Committee on Vaccination at the Robert Koch Institute in Germany recommend vaccination with the tetravalent live attenuated vaccine Qdenga for certain travelers over the age of 4 years prior to exposure in dengue-endemic regions, and for laboratory personnel outside of dengue-endemic regions [53, 54].

CONCLUSIONS

Environmental factors and climate change significantly influence the rise of dengue fever by creating favorable conditions for mosquito breeding and transmission. Climate change is one of the main factors behind the global increase in dengue cases. To reduce the threat of dengue in a warming world, effective monitoring, mosquito control methods, and public health planning informed by climate data are essential. While there is debate about urbanization and poor sanitation, rainfall patterns and higher temperatures may also play a role in the spread of dengue.

Competing interests

The authors declare that have no competing interests.

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